ELECTRIC POWER RESEARCH INSTITUTE

OVERVIEW OF POLLINATOR-FRIENDLY SOLAR ENERGY

December 2019

TABLE OF CONTENTS

INTRODUCTION

The solar energy industry in the United States is undergoing considerable expansion. The recent growth in solar installations is driven in part by federal and state policies towards renewable energy, and by the public demand for more sustainable sources of energy. The Department of Energy's (DOE's) Sunshot Vision Study set the goal for the United States that 14% (329 GW) of the nation's electricity come from solar generation by 2030 [1]. The majority of the solar generation (63%) would result from ground-mounted and concentrating solar power with the remaining solar production (37%) coming from rooftop photovoltaics. For utilities procuring solar electric generation either through direct ownership or through purchase power agreements, the land under and around these sites presents an opportunity to realize ancillary benefits to ecosystems. This Technical Brief provides a summary of the key considerations related to "pollinator-friendly solar."

While solar power is important for reducing air and greenhouse gas emissions, there are some negative environmental impacts that need to be considered. One of these potential impacts is disruption to habitat and biodiversity. A common proxy for anticipating habitat impacts is to estimate the total acres that will be changed due to solar installations. Ground-mounted solar, for example, has historically required approximately 8-10 acres (3-4 hectares) of land per megawatt. If we assume that same generation efficiency and apply the projected ground-mounted installations, land requirements could equal approximately 1.8 million acres (0.73 million hectares) [2], [3] in the United States. With the anticipated expansion of solar power, impacts to biodiversity are a growing concern, as expressed in recent scientific publications:

"Renewable energy development is an arena where ecological, political, and socioeconomic values collide. Advances in renewable energy will incur steep environmental costs to landscapes in which facilities are constructed and operated. Scientists—including those from academia, industry, and government agencies—have only recently begun to quantify trade-offs in this arena, often using ground-mounted, utility-scale solar energy facilities (USSE, ≥1 megawatt) as a model [4]."

Ground-Mounted Utility-Scale Solar

Ground-mounted utility-scale solar energy (USSE) generate at least 1 megawatt of electricity. Traditional ground-mounted solar systems anchor to the ground to hold large numbers of panels. Two rails usually support each panel, with steel beams driven into the ground to anchor a racking system that is attached to the rails. Anchor systems don't always need to penetrate the earth, as may be the case with brownfields where there is a cap covering the land.

Pollinators are one group sensitive to continued habitat loss and are experiencing global population declines [5], [6]. Research has documented that native bees, honey bees, and butterflies have all experienced population declines over the last decade [7], [8], [9], [10]. Precipitous declines, for example, have been reported for monarch butterflies, threatening the long-term viability of the spe-

cies [11]. Habitat loss, climate change, and chemical exposure, in addition to pathogens and pests, are cited as factors contributing to declining pollinator populations [12], [13], [14], [15], [16]. Urban, agricultural, and even natural landscapes are increasingly impacted by anthropogenic alterations that have negative effects on pollinators and broader biodiversity.

Ground-mounted utility-scale solar energy (USSE) sites are particularly large and serve as an example of an anthropogenic disturbance that may cause impacts on pollinator populations. If not considered during design and construction, solar projects can result in loss of habitat, destruction of nesting sites, soil compaction that reduces access to pollinator nesting habitat, and increase in invasive species that displace native flowering food resources [17], [18]. Siting and construction activities may further impact pollinators by fragmenting existing habitat or creating barriers to movement. This is an issue because isolated pollinator populations experience reduced survival, reproduction, and gene flow.

Once solar sites are installed, maintenance activities need to be considered in relation to the surrounding ecosystem. This is particularly true for vegetation management around the solar panels. For example, broad spectrum herbicides for controlling vegetation could decrease access to pollen and nectar resources by eliminating perennial native flowers and other flowering species. While mowing is often preferred from an ecological standpoint to chemical controls, improperly timed mowing during flower bloom can have detrimental effects on pollinators.

Hosting Honey Bees at Solar Farms

Based in Medford, Oregon, Old Sol Apiaries places honey bee boxes around solar panels and later harvests the honey (Fig 1). The sites also serve as important resting areas for bees when they are not otherwise rented to farmers for pollination services. Founder and CEO, John B. Jacob, is now serving his second term as executive director of the Oregon State Beekeepers Association advocates for honey bee health and sustainable beekeeping practices. Because the bees and honey are agricultural products, the practice of raising bees around solar panels is also known as “Agrivoltaics”.

The following summary was provided by Old Sol Apiaries:

“Native bees and managed bees (i.e., honey bees) are in crisis and urgently need more acres of healthy habitat. As a society we’ve created a system that encourages turfgrass—there’s more than 40 million acres (16 million hectares) of it nationwide—but these landscapes are barren of the nectar and pollen that bees need to survive and simply don’t stand up to the drought and deluge weather that’s become the new normal. Pollinator-friendly solar landscapes provide a number of functional benefits and beekeepers stand at the ready to strongly support solar farms when the vegetation under and around the panels provides a meaningful source of food for pollinators.

Throughout this venture we have learned a lot. Though not a complete list, here are the most important lessons for electric utilities pursuing solar development:

Vegetation: Many solar farms are replacing non-native corn, soybeans, and other crops. Using seed mixtures with non-native legume species, such as clovers, may be the best option in terms of floral abundance and cost. Local partners will be able to select plant species that are not considered invasive and meet specific performance needs.

Some PV designs can lead to extra O&M costs: If your solar panels are low to the ground or if the rows of your solar panels are blocked by steel cable trays or hanging wires, you should be prepared for 20-30 years of high operations costs. Having studied the design and vegetation management practices across numerous solar projects, the best designs have PV panels at least 36 inches above the ground at the lower edge and bury the conduit and wiring.

Pay your beekeeper and expect them to use best practices: Raising bees is a tough business. There are ecological and economic challenges. Pay bee keepers well and require them to use best practices that protect the bees as well as your site. Your solar sites can provide important resting places for our bees. You get public relations benefits and maybe some honey!

The success of pollinator friendly solar will be of paramount importance as pollinators and habitat continue to decline, and as solar continues its rapid growth. The synergy between solar and beekeepers can be advantageous to both parties.”

Figure 1. Honey bee boxes being managed near solar panels (Photo Credit: Dennis Schroeder)

If challenges present themselves, if they are properly considered and managed, solar installations can contribute to pollinator conservation through proper siting, plant and seed selection, and site maintenance. Power companies, solar developers, and solar plant owners have opportunities to promote pollinator conservation at solar sites by creating and managing habitat.

CONSIDERING POLLINATORS DURING DESIGN, CONSTRUCTION AND MAINTENANCE

Below are some of the basic considerations for supporting pollinators during site planning, construction, and maintenance.

Design

While solar sites offer an exciting opportunity for pollinator conservation, they also pose unique challenges to the establishment of pollinator habitat. Panel height, shading effects, and the spatial arrangement of panels are important considerations when developing seed mixes and maintenance plans. Solar panels, for example, are often short, which limits the use of some regionally-specific native plants that are most supportive of native pollinators. Many native plants will grow taller than commonly used panels, which are 18 inches in height. Depending on the height of the panel and the height of the plant, there is potential for plants to shade panels and reduce energy generation. Solar panels can also impact plant growth. When it rains, panels divert water, creating variable soil moisture conditions across the site. Panels can also affect the growth of plants due to shading. Panels will unevenly cast shade in the rows between panels throughout the day, with the heaviest shade occurring directly under panels. Variable shade and soil moisture are two factors that make plant selection more difficult at solar sites, and as a result, will need to be tailored to meet regional environmental conditions.

Developers should consider panel height and spacing when developing the site to be compatible with pollinator-friendly solar and to ease future maintenance activities. Species selection and the planting design may require taller plants to be planted in rows next to the taller side of panels where they will not cast shadows onto panels. Similarly, taller flowers could simply be planted along the edges of solar sites, removing energy generation concerns yet still providing valuable food and nesting resources to pollinators. Shorter grasses and lower growing flowers could be located under panels and along the lower edge of panels. Finally, the use of warm season native plants, as opposed to cool season non-native grasses, may reduce mowing frequency, potentially reducing maintenance and labor costs. While many current pollinator-friendly solar plantings place the native plants underneath and between panels, the planting design could place buffers or "hedgerows" of highly diverse plant mixes around solar sites and realize similar pollinator benefits, although field studies are currently lacking to compare the various planting approaches. (Figure 2).

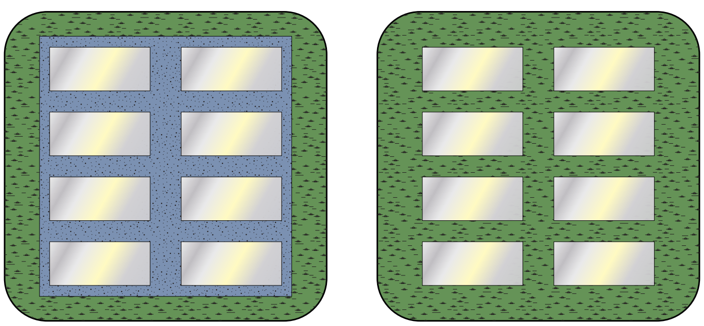


Figure 2. Possible panel-vegetation designs.
Left: Solar panel design with gravel between panels and highly diverse pollinator plantings surround site (e.g., hedgerow).
Right: Solar panel design with pollinator plantings under and around panels.

Irrigation needs are also important to consider. Vegetation mixes in desert areas will be quite different than mixes in regions that are flush with rain. If projects require active irrigation to support pollinator-friendly vegetation, costs will increase, as will the overall environmental footprint of site maintenance due to water consumption and associated energy usage for water pumping. Such tradeoffs are complex and need to be considered on a site-specific basis.

Construction

The construction phase of utility-scale solar often includes removing existing vegetation, stripping topsoil, and grading the site. These activities eliminate pollinator habitat, compact the soil, and remove valuable top soil needed for revegetation [19]. Construction activities can attempt to conserve existing native plant communities and avoid removing topsoil that contains nutrients and microorganisms critical to the successful re-establishment of native habitat (Table 1). Prioritizing the protection of existing pollinator habitat through the selection of sites planned for development is one of the most important actions to consider. Floristically diverse habitats, such as grasslands and wetlands, may need to be avoid, as well as existing foraging and nesting habitat.

Table 1. Construction and maintenance activities that support pollinators at solar sites

Siting and Construction	Maintenance Activities
Avoid critical pollinator habitat	Avoid mowing during blooming
Do not remove top soil	Avoid use of herbicides
Retain existing native vegetation	Avoid use of insecticides
Do not overly grade the site	Remove invasive species
Avoid soil compaction	Mow in late spring to avoid harming ground nesting overwintering pollinators

Maintenance

Once pollinator habitat has been established, maintenance activities can be designed to protect pollinators. Herbicide applications, if used, should avoid native flowering plants, but may be necessary if invasive species have been established on the site. Invasive species should be removed immediately from pollinator habitat, as these species can establish, spread, and quickly outcompete native plants. In this situation, spot spraying with the use of a backpack sprayer will enable targeted applications to invasive plants, while still protecting native species. Frequent mowing will be required during the first several years while the native vegetation establishes. Mowing reduces competition with weedy species and prevents the undesirable species from setting seed. However, once habitat is established, mowing frequencies can be reduced to avoid removal of native flowers during bloom. Many bees nest in the soil, whereas butterflies and moths overwinter on native vegetation. As a result, mowing in spring is recommended, as opposed to the fall, as it will preserve pollinators overwintering in the restored habitat.

Increasingly, grazing animals are being used to "mow" vegetation around the panels, known as "solar grazing." Initial attempts to use grazing animals have already informed best practices. For example,

damage has been caused from goats climbing onto the panels and from cows scratching their backs on the supporting rods. Sheep, on the other hand, seem to be working well for solar grazing. The American Solar Grazing Association (https://solargrazing.org/) was founded as a New York not-for-profit to inform the practice and service solar grazing providers are being developed (i.e. New Jersey venture Solar Sheep, LLC https://www.solarsheepllc.com/).

Remember Pollinator Basics

Pollinators depend on floral resources for pollen and nectar. Adult bees, for example, feed on both nectar and pollen. Female bees also collect pollen to provision their nests, on which the developing bee larva feeds. Both the abundance and richness (i.e., number of species) of flowers is important to supporting pollinator populations (Table 2) [20], [21] [22].

When selecting species for pollinator habitat, the use of native flowers is preferable over non-native and ornamental flower species. Studies have found native flowers are often more attractive to pollinators as compared to ornamental varieties [23], [24], [25]. In addition, research has demonstrated ornamental flowers lack the pollen and nectar resources provided by native flowers [26, [27]. Native plants are also adapted to local growing conditions, including soil type, temperature, and moisture levels, meaning these species are more likely to establish and survive especially under harsh growing conditions. As a result, when designing a seed mix for revegetation of a solar site, carefully select a combination of flowering native plants that will provide season-long access to pollen and nectar resources, ensuring both flower abundance and richness are represented from the early spring through the late fall.

Flower color and shape influence visitation by pollinators. Flower color is another element to consider when designing a mix. Pollinators, especially bees, preferentially visit flowers based on flower color [28], [29]. Research has found bees prefer yellow, blue, and pink flowers, while butterflies often visit yellow, pink, and purple flowers [28]. Incorporating a diversity of flower shapes is also important when designing pollinator habitat [30]. The shape of the flower will determine which pollinators can access pollen and nectar resources based on the mouthparts of the pollinator. For example, some species such as bumble bees have long-tongues, meaning these bees can access the nectar in tubular shaped flowers, while short-tongued bees like sweat bees have to visit open shaped flowers. Butterflies, with their long siphoning mouthparts, can visit both tubular and open shaped flowers, while wasps and flies have mouthparts requiring easy access to nectar and pollen often visiting plants in the Asteraceae, Apicacea, and Lamiaceae plant families. Finally, pollinator habitat should also include larval host plants, which is a particularly important characteristic when creating habitat for butterflies.

Table 2. Elements of a pollinator-friendly plant community

Pollinator Friendly Plantings include:	
High flower diversity (20+ species)	Use native plants
High flower area	Avoid ornamental species
Season long flowering	Select flowers with demonstrated attractiveness to pollinators
Nesting sites	Range of flower colors
Larval host plants	Range of flower shapes

Reusing Land: Brownfields to Brightfields

"Brightfields" is an initiative launched by the U.S. Department of Energy (DOE) in August 1999, aimed at using former industrial sites contaminated with toxic waste for producing pollution-free solar energy. This concept attempts to address three of the nation's greatest challenges: climate change, urban revitalization, and toxic waste cleanup. As one example, the Scituate Board of Selectman in the Commonwealth of Massachusetts awarded the contract to build a solar photovoltaic array atop the Town's capped landfill to Brightfields Development LLC in 2011. The 3 megawatt (MW) solar array was the second renewable energy project completed by the Town of Scituate, which also commissioned a 1.5 MW wind turbine in March of 2012. (Source: http://solar-brownfields.com/projects/scituate-solar-i). With the decreasing availability of unencumbered land in the United States, there is interest in using more brownfield sites for placement of solar panels. A brownfield type relevant for the electric power industry are capped coal ash ponds. EPRI has been investigating options for establishing solar fields and restoring ecological benefits on these sites by replanting the areas with pollinator friendly vegetation underneath and around the panels. Unique considerations include root penetration of the underlying cap that is typically covers the brownfield, soil loads on the cap necessary to support vegetative growth, and long-term maintenance of both the vegetation and solar panels.

Case Study: Dairyland Power Cooperative Adding Solar and Pollinators

In 2016, Dairyland Power Cooperative (Dairyland) entered into an agreement with ENGIE (then SoCore Energy) and CMS Energy to purchase 25 megawatts of energy from 18 solar projects located throughout Dairyland's service territory of Wisconsin, Minnesota, Iowa, and Illinois. Each of the solar generation sites provides beneficial pollinator habitat, with the 18 sites equating to approximately 250 acres (101 hectares) of newly created pollinator habitat.

Prairie Restorations, Inc. (PRI) designed and installed the sites, which were seeded with native prairie seed mixes especially suited to the specific geographic location and conditions at each site (Figure 3). The seed mixes included both common and whorled milkweed to aid in monarch butterfly conservation. PRI continues to maintain the sites by conducting two to three site visits a year to mow, spray, re-seed, and remove weeds as necessary.

Figure 3. Dairyland solar site with native prairie habitat planted between solar panels. Photo: Brad Foss, Dairyland

Procurement of Pollinator-Friendly Solar

Whether a power companies procures solar power through a power purchase agreement (PPA) or are the long-term owner of a site, they may include pollinator friendly language in the vegetation section of a request for proposals (RFP) from vendors and contractors. By including language in the RFP process, utility companies can convey that their solar energy will yield ancillary benefits. In doing so, they can gain favor and goodwill from agricultural, conservation, and environmental stakeholders, as well as from the general public.

Here are examples of how to include pollinator preferences in an RFP:

- [Utility Name]'s customers expect that we will produce and deliver power in ways that protect the environment and the communities we serve. Our state's Department of Natural Resources and Department of Agriculture agree that increasing the abundance of flowering landscapes helps ensure sustainable populations of pollinators and other wildlife.
- [Utility Name]'s customers expect that we will produce and deliver power in ways that protect the environment and the communities we serve. Our state's Department of Natural Resources and Department of Agriculture agree that increasing the abundance of flowering landscapes helps ensure sustainable populations of pollinators and other wildlife. In addition to a narrative regarding the vegetation design and management plan for the solar array, RFP responses shall disclose the expected score, or range for a final score, on the attached Pollinator-friendly solar scorecard.
- [Utility Name]'s customers expect that we will produce and deliver power in ways that protect the environment and the communities we serve. Our state's Department of Natural Resources and Department of Agriculture agree that increasing the abundance of flowering landscapes helps ensure sustainable populations of pollinators and other wildlife. All other factors being equal, [Utility Name] prefers solar projects that score 70 or above on the included Pollinator-friendly Solar planning/assessment form. In addition to a narrative regarding the

vegetation design and management plan for the solar array, RFP responses for use of arable land shall disclose the expected score, or range for a final score, on the attached Pollinator-friendly solar scorecard.

Beyond Pollinators

Solar sites that support pollinator friendly habitat also provide other ecological benefits. Native habitat that benefits pollinators offers food and nesting resources to other species of conservation concern such as grassland birds, bats, and small mammals. Native plants, especially grassland species, are drought and fire adapted, having roots that reach depths ranging from 5 feet up to 20 feet [31]. A consequence of a deeply rooted plant community is reduced soil erosion and water runoff from sites restored with grassland species [18] [32]). While solar sites benefit directly from increased species conservation, reduced soil erosion and decreased water runoff are added ecological benefits. The benefits of using native plant species for stormwater management at solar fields are discussed in *Solar-Stormwater Nexus: An Overview of Regulatory and Permitting Issues Related to Developing Utility-Scale Solar Projects* (EPRI, Oct 2018 Report ID 3002014508). In addition to local site benefits, the establishment of pollinator habitat can positively impact the surrounding landscape, such as neighboring agricultural sites.

Lands adjacent to solar sites, such as agricultural fields, may experience greater pollination and natural pest suppression services resulting from the increased pollinator and beneficial insect populations being supported by the native habitat at neighboring solar sites [33]. Pollinator habitat may also improve the aesthetics of the site by incorporating native flowers that bloom through the growing season and that support charismatic wildlife species, including bees, butterflies, and birds. Landscape aesthetics, while more difficult to quantify, can increase public support for new developments. Finally, solar sites that incorporate native habitat may consider other uses compatible with the establishment of native vegetation, such as grazing with sheep or crop production [7]. Solar developments that incorporate multiple uses into their site plan, such as a diversified farm, may receive increased community support compared to a traditional solar site that is not complementary to the surrounding ecosystem.

The Business Case for Pollinator-Friendly Solar

Solar sites that support pollinator conservation can create advantages for business activities. Several states have recently passed legislation designating pollinator-friendly solar if developers meet vegetation and maintenance standards for the site. Several states (i.e. MN, IL, NY, ME, VT) have developed pollinator scorecards that provide guidelines for seed mixes and management practices that companies follow to obtain the pollinator friendly designation (see Fig 5). Acquiring the pollinator friendly label for a project may positively impact the permitting process and reduce litigation risk by demonstrating increased environmental benefits and public support.

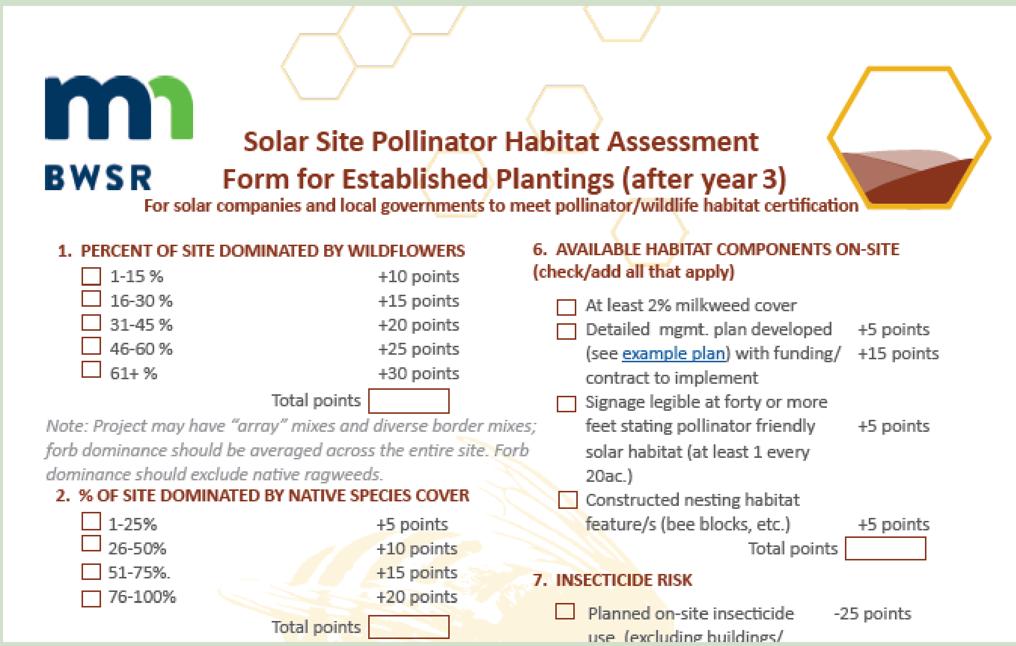
Reduced cost is another potential benefit to the long-term operations and maintenance of the site. While the cost of native seed is typically higher compared to turf grass, long-term maintenance costs for native mixes can be lower due to reduced mowing frequency, fewer herbicide treatments for weed control, and reduced reseeding after erosion or dieback caused from drought. NREL recently compared the performance of warm-season native grasses to cool-season non-native grasses at a solar facility in Colorado and found that native grasses provided the highest total percent cover and lowest occurrence of weeds [19]. Sites that are susceptible to soil erosion during heavy rains may also reduce maintenance costs by using a native plant mix, which research has found increases infiltration and lowers stormwater runoff [34].

It is important to highlight that the cost savings for pollinator-friendly solar, if realized, will be during the long-term maintenance of the site. The use of native seeds can be more costly during installation, as compared to turf grass. Also, while there is anecdotal evidence pointing to reduced costs for managing these sites compared to traditional solar sites, currently there is limited quantitative analysis that supports this determination that takes into account the investment break-even point.

While pollinator-friendly solar will not make sense in all situations, it may have business benefits compared to traditional solar via improved aesthetics, biodiversity support, reduced stormwater and soil runoff, and lower long-term maintenance costs.

Case Study: Xcel Energy Requiring Vegetation Disclosure in Solar RFPs to Enable Pollinator Friendly Solar Sites

In October 2018, Excel Energy announced it will be the first utility in the United States to require disclosure of the types of vegetation that will be planted with solar sites in all its future requests for Requests for Proposals (RFPs). The utility plans to add 2,600-3,000 MW of solar generation by 2030. All new solar projects will be required to disclose a scorecard for pollinator friendly sites. Site scorecards are based off Minnesota's solar site 2016 management legislation that establishes "voluntary solar site management practices" under which projects can be categorized as "pollinator friendly" if they meet certain vegetation standards (Minnesota Statutes, chapter 216B.1642). According to Matt Lindstrom, a spokesman for the utility, "Xcel Energy has a long history of supporting pollinators and developing pollinator friendly habitats at our power plants, substations, and along our transmission lines. We want to ensure that there will be land for pollinators to grow and thrive in the area we serve, while we deliver clean renewable energy for customers." (Printed with permission from Excel).



BWSR

Solar Site Pollinator Habitat Assessment Form for Established Plantings (after year 3)

For solar companies and local governments to meet pollinator/wildlife habitat certification

1. PERCENT OF SITE DOMINATED BY WILDFLOWERS

- ☐ 1-15 % +10 points
- ☐ 16-30 % +15 points
- ☐ 31-45 % +20 points
- ☐ 46-60 % +25 points
- ☐ 61+ % +30 points

Total points ☐

Note: Project may have "array" mixes and diverse border mixes; forb dominance should be averaged across the entire site. Forb dominance should exclude native ragweeds.

2. % OF SITE DOMINATED BY NATIVE SPECIES COVER

- ☐ 1-25% +5 points
- ☐ 26-50% +10 points
- ☐ 51-75%. +15 points
- ☐ 76-100% +20 points

Total points ☐

6. AVAILABLE HABITAT COMPONENTS ON-SITE (check/add all that apply)

- ☐ At least 2% milkweed cover
- ☐ Detailed mgmt. plan developed (see example plan) with funding/ contract to implement +5 points +15 points
- ☐ Signage legible at forty or more feet stating pollinator friendly solar habitat (at least 1 every 20ac.) +5 points
- ☐ Constructed nesting habitat feature/s (bee blocks, etc.) +5 points

Total points ☐

7. INSECTICIDE RISK

- ☐ Planned on-site insecticide use (excluding buildings/ -25 points

Figure 4. Minnesota Pollinator Friendly Scorecard, Minnesota Board of Water and Soil Resources.
Source: https://bwsr.state.mn.us/sites/default/files/2018-12/established_project_assessment_form.pdf

Case Study: Connexus Energy Plants Low-Growing Flowering Meadow Around Solar Array at its Headquarters

Serving 132,000 members, Connexus Energy is the largest electric cooperative in Minnesota. In 2014 its 245-kW solar array on 1.2 acres (0.5 hectares) of land adjacent to Connexus' headquarters was the largest coop community solar array in the state. Designed to have 4-6 inches of class 5 gravel under and around the panels, as the project moved forward Connexus' Communication and Marketing leads made the case for the site to be seeded with a low-growing flowering meadow. At the time the decision was entirely based on aesthetics—the site is visible to all visitors as well as being outside the windows of a main conference room. Now well into its fourth year of establishment, the site gets just one annual mow and has become a national model featured in *National Geographic*, *Martha Stewart*, *Modern Farmer*, and other publications.

Figure 5: Connexus Solar Wise solar array

SUMMARY

Power companies and solar developers have opportunities to promote pollinator conservation at solar sites by creating and managing pollinator habitat. The approach to meeting multiple environmental goals at one time will become more important in the coming decade. Greenhouse gas emission concerns may need to be addressed while directly restoring habitat and waterways, for example. Interest in pollinator-friendly solar is fueled by limited land for utility-scale solar, stakeholder concerns for loss of farmland due to solar developments, ascetics of large solar fields (i.e., Not in My Backyard (NIMBY) issues), and associated environmental concerns for biodiversity loss and stormwater pollution.

However, certain considerations are necessary to create and manage effective solar-pollinator projects, including appropriate design, installation, and maintenance. And, while there is anecdotal evidence pointing to reduced costs for managing these sites as compared to the cost of managing traditional solar sites, there was no published quantitative analysis to back-up this determination.

Future research necessary to better understand pollinator-friendly solar opportunities includes: cost-benefit analysis, vegetative design optimization plans, on-site species assessments to confirm pollinator benefits, and testing of electricity generation efficiency given plant shadowing and pollen residue effects on the panels. Overall, when properly considered and managed, solar installations hold great potential to contribute positively to pollinator conservation while also meeting broader societal demands for renewable energy.

ACKNOWLEDGMENTS

The EPRI primary authors, Ashley Bennett and Jessica Fox, recognize input provided by Rob Davis, Director, Center for Pollinators in Energy at Fresh Energy. The following EPRI experts were also very helpful during report writing: Sean Hackett, Cara Libby, Michael Bolen, and Ken Ladwig. Editors were Ellen Donnelly and Justin Sauble. Finally, we are appreciative of the support of the EPRI Power-in-Pollinators Initiative, the largest collaboration in North America of electric power companies considering their role in pollinator conservation; a full list of participating companies is posted at www.epri.com/pollinators.

REFERENCES

1. DOE 2012. United States Department of Energy, Sunshot Vision Study. February 2012. https://www.energy.gov/sites/prod/files/2014/01/f7/47927.pdf
2. Ong S, Campbell C., Denholm P, Margolis R, and Heath G, "Land Use Requirements for Solar Power Plants in the United States," NREL, June 2013.
3. Hartmann, et al., "Understanding Emerging Impacts and Requirements Related to Utility-Scale Solar Development," Argonne National Laboratory Report ANL/EVS-16/9, September 2016.
4. Moore-O'Leary, et al., "Sustainability of utility-scale solar energy – critical ecological concepts," *ESA Journal*, August 14, 2017, https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1002/fee.1517
5. Kremen C, Ricketts T. Global perspectives on pollination disruptions. *Conserv Biol*. 2000; 14(5): 1226-1228.
6. Kennedy CM, Lonsdorf E, Neel MC, Williams NM, Ricketts TH, Winfree R, et al. A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. *Ecol Lett*. 2013; 16(5): 584-599.
7. Burke MJ. Mutually-beneficial renewable energy system. *Relations*. 2018. doi: http://dx.doi.org/10.7358/rela-2018-001-burk.
8. Bartomeus I, et al., "Historical Changes in Northeastern US Bee Pollinators Related to Shared Ecological Traits," Proceedings of the National Academy of Science of the United States of America, February 2013. www.pnas.org/cgi/doi/10.1073/pnas.1218503110.
9. Smith KM, Hoh EH, Rostal MK, Zambrana-Torrelio CM, Mendiola L, Daszak P. Pathogens, pests, and economics: drivers of honey bee colony declines and losses. *EcoHealth*. 2014; DOI: 10.1007/s10393-013-0870-2.
10. Oberhauser K, et al. A trans-national monarch butterfly population model and implications for regional conservation priorities. *Ecol Entom*. 2017; 42: 51-60.
11. Schultz CB, Brown LM, Pelton E, Crone EE. Citizen science monitoring demonstrates dramatic declines of monarch butterflies in western north america. *Biological Conservation*. 2017; 214: 343-346.
12. Potts SG, Biesmeijer JC, Kremen C., Neumann P, Schweiger O, Kunin WE. Global pollinator declines: trends, impacts, and drivers. *Trends Ecol*. 2010; 25(6): 345-353.
13. Vanbergen AJ, Insect Pollinator Initiative. Threats to an ecosystem service: pressures on pollinators. *Front Ecol Environ*. 2013; 11(5): 251-259.
14. Goulson D, Nicholls E, Botias C, Rogheray EL. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers, *Science*. 2015: 347(6229), 1255957.
15. Belsky J and Joshi N, "Assessing Role of Major Drivers in Recent Decline of Monarch Butterfly Population in North America," *Frontiers in Environmental Science*, Vol. 6, Article 86, August 2018.
16. Agrawal AA, Inamine H. Mechanisms behind the monarch's decline. *Science*. 2018: 360(6395); 1294-1296.
17. Lovich J and Ennen R, "Wildlife Conservation and Solar Energy Development in the Desert Southwest, United States," BioScience, Vol. 61, No. 12, December 2011.
18. Hernandez-Santana V, Zhou X, Helmers MJ, Asbjornsen H, Kolka R, Tomer M. Native prairie filter strips reduce runoff from hillslopes under annual row-crop systems in Iowa, USA. *J of Hydrology*. 2013; 477:94-013.
19. Beatty B, Macknick J, McCall J, Baus G. Native vegetation performance under a solar pv array at the national wind technology center. NREL/TP-1900-66218.
20. Bennett AB, Gratton C. Floral diversity increases beneficial arthropod richness and decreases variability in arthropod community composition. *Ecol Appl*. 2013; 23(1): 86-95.
21. Simao MCM, Matthijs J. Perfecto I. Experimental small-scale flower patches increase species density but not abundance of small urban bees. *J Appl Ecol*. 2018; 55(4): 1759-1768.
22. Bennett AB, Lovell S. Landscape and local site variables differentially influence pollinators and pollination services in urban

agricultural sites. PLoS ONE 14(2): e0212034. https://doi.org/10.1371/journal.pone.0212034

23. Garbuzov M, Samuelson EEW, Ratnieks FL. Survey of insect visitation of ornamental flowers in Southover Grange garden, Lewes, UK. *Insect Science*. 2015; 22(5):700-705.
24. Salisbury A, et al. Enhancing gardens as habitats for flower-visiting aerial insects (pollinators): should we plant native or exotic species? *J Applied Ecol*. 2015; 52: 1156-1164.
25. Garbuzov M, Alton K, Ratnieks FLW. Most ornamental plants on sale in garden centers are unattractive to flower-visiting insects. PeerJ. 2017; e3066.
26. Corbet SA, et al. Native or Exotic? Double or Single? Evaluating Plants for Pollinator-friendly Gardens. Annual of Botany. 2001; 87(2):219-232.
27. Mach BM, Potter DA. Quantifying bee assemblages and attractiveness of flowering woody landscape plants for urban pollinator conservation. PLOS ONE 13 (12). 2018: e0208428. https://doi.org/10.1371/journal.pone.0208428
28. Chittka L and Raine N, "Recognition of Flowers by Pollinators," *Current Opinion in Plant Biology*, 9:248-425, 2006.
29. Reverte S, Retana J, Gomez JM, Bosch J. Pollinators show flower colour preferences but flowers with similar colours do not attract similar pollinators. Annuals of Botany. 2016; 118:249-257.
30. Cepero LC, Rosewald LC, Weiss MR. The relative importance of flower color and shape for the foraging monarch butterfly (Lepidoptera: Nymphalidae). 2015; 28 (4): 499-511.
31. Packard S, Mutel CF. The tallgrass restoration handbook for prairies, savannas and woodland. 1997. Island Press, Washington DC.
32. Schulte LA, Niemi J, Helmers MJ, Liebman M, Arbukle G, James DE, et al. Prairie strips improve biodiversity and the delivery of multiple ecosystem services from corn-soybean croplands. PNAS. 2017; 114(50): E10851.
33. Walston LJ, Mishra SK, Hartmann HM, Hlohowskyj I, McCall J, Macknick J. Examining the potential for agricultural benefits from pollinator habitat at solar facilities in the United States. *Envrin Sci Technol*. 2018; 52:7566-7576.
34. Osouli A, Bloorchian AA, Grinter M, Alborzi AA, Marlow SL, Ahiablame L, Zhou J. Performance.

The Electric Power Research Institute (EPRI) Prepared this Report.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

Note

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

EPRI RESOURCES

Jessica Fox, *Senior Technical Executive*
650.855.2138, jfox@epri.com

Ashley Bennett, *Technical Leader*
865.218.8049, abennett@epri.com

EPRI's Power-in-Pollinator Initiative
More information at www.epri.com/pollinators

3002014869 December 2019

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com